OPEN-FILE REPORT 98-12

SEISMIC HAZARD EVALUATION OF THE AZUSA 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

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CONTENTS

ILLUSTRATIONS

PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

> BPS Reprographic Services
> 149 Second Street
> San Francisco, California 94105
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Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

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Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage:
http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Azusa 7.5-minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Azusa 7.5-Minute Quadrangle, Los Angeles County, California

By
Ralph Loyd and Christopher J. Wills

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Azusa 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated granular sediments within the upper 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Azusa Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Azusa Quadrangle covers an area of about 62 square miles in central Los Angeles County. Part of the densely populated San Gabriel Valley spreads across the southern quarter of the quadrangle. The remaining three-quarters of the quadrangle consists of the rugged terrain of the central San Gabriel Mountains. Most of mountainous part of the quadrangle lies within the Angeles National Forest, except for a fringe of frontal ridges that typically extends less than a mile north of the valley floor. Parts of the cities of Monrovia, Duarte, and Irwindale, as well as the entire City of Bradbury, lie within the valley part of the quadrangle. Primary transportation routes in the quadrangle area are oriented east-west in the San Gabriel Valley. These include major through streets, such as Foothill Boulevard and Duarte Road, and the Foothill Freeway (I-210). Access to the area from the south is via the San Gabriel River Freeway (I-605). San Gabriel Canyon Road (State Highway 39), a major route into the San Gabriel Mountains, leads northward from Azusa.

The San Gabriel Mountains rise very abruptly from the valley and reach elevations of over 5400 feet at Monrovia Peak in the northwestern part of the quadrangle. The mountains are composed of igneous and metamorphic rocks that range in age from Precambrian through Cretaceous. The San Gabriel Mountains of today rose to their current elevation beginning in Pleistocene time as the ancient rocks were thrust upward and toward the south along range-bounding faults belonging to the Sierra Madre Fault system. Slopes in the crystalline bedrock are “exceptionally steep and insecure” (Muir, 1877), which, along with periodic torrential rains, leads to periodic debris flows and floods in the valley.

Streams draining from the San Gabriel Mountains have deposited alluvial fans in the valley. The largest stream in the mountains, the San Gabriel River, drains a watershed of over 200 square miles. The river enters the valley west of Azusa, and has deposited a large alluvial fan that extends to the south across the valley. The central part of this fan is used for flood control basins, including the Santa Fe Flood Control Basin, ground-water recharge, and sand and gravel mining. The developed areas of the valley are built on the edges of this fan and on the smaller alluvial fan from Sawpit Canyon to the west in Monrovia.

GEOLOGIC CONDITIONS

Surface Geology

In preparing the Quaternary geologic map for the Azusa Quadrangle, geologic maps prepared by Dibblee (unpublished), Morton (1973), Crook and others (1987), and McCalpin (unpublished) were referred to. We began with the maps of McCalpin (unpublished), and Morton (1973) as files in the DMG Geographic Information System. Morton (1973) mapped the north half of the quadrangle showing the bedrock geology in great detail. McCalpin mapped the Quaternary units, primarily using geomorphic expression and soil surveys to map and determine the ages of various Quaternary geologic units. He also incorporated the mapping of Crook and others (1987), especially for areas of artificial fill, which McCalpin had not mapped originally (McCalpin, personal communication, 1998). McCalpin's mapping also used the SCAMP nomenclature for geologic units (Morton and Kennedy, 1989). Morton's (1973) mapping of bedrock also showed the geologic boundaries between the bedrock and Quaternary units with more detail than McCalpin. The completed map of Quaternary geology primarily uses boundaries between the geologic units as mapped by Morton (1973) in the mountainous areas and McCalpin in the valley, with unit designations modified somewhat from McCalpin based on Crook and others (1987). The Quaternary geologic map of the Azusa Quadrangle is reproduced as Plate 1.1.

The Quaternary geologic map (Plate 1.1) shows that the valley areas of the Azusa Quadrangle are covered by alluvial fans of various ages, including remnants of very old fans along the front of the San Gabriel Mountains, older alluvial surfaces, and the young San Gabriel River fan. The San Gabriel River fan is composed of gravel and mixtures of sand and boulder gravel, reflecting the major flows on the San Gabriel River. Smaller fans, such as that of Sawpit Canyon, are typically composed of sand and gravel. In the Azusa Quadrangle, the alluvial units have been subdivided into two generations of very old alluvium (Qvoa, Qvoa1, Qvoa2), older alluvium (Qoa and Qof1), four generations of young alluvium (Qya4 - Qya1) and active wash and fan deposits (Table 1.1).

Subsurface Geology and Geotechnical Characteristics

Subsurface data used for this study include borehole logs collected from the California Department of Transportation (CalTrans), the California Department of Water Resources, the Regional Water Quality Control Board, Los Angeles County Flood Control files by U.S. Geological Survey staff, DMG files of seismic reports for hospital and school sites, and a database of shear wave velocity measurements originally compiled by Walter Silva (Wills and Silva, 1998).

	Alluvial Fan Deposits	**Alluvial Valley Deposits**	**Age**
Active	Qf- active fan		
	Qw- active wash		
Young	Qyf1, Qyf2, Qyf3, Qyf4	Qya, Qya1, Qya2, Qya3, Qya4	Holocene?
Old	Qof, Qof1	Qoa	Pleistocene?
Very Old	Qvof	Qvof	Pleistocene

Some unit names include the “characteristic grain size” (e.g. Qyf2a, Qofg)
b: boulder gravel, g: gravel, a: arenaceous (sand), s: silty, c: clayey.

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) nomenclature used in the Azusa Quadrangle.

Five logs of boreholes drilled within the study area were collected, examined and related to the surficial geologic map units. Only a few borehole logs were collected for the Azusa Quadrange study because available hydrologic data showed that most of the area covered by the quadrangle has been characterized by deep ground-water levels throughout historical time. Since such areas do not contain soils susceptible to liquefaction, soil analyses is not needed.

Locations and geotechnical data from borehole logs were entered into DMG’s Geographic Information System (GIS). Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections using data reported on the borehole logs enabled staff to relate soil engineering properties to various depositonal units, to correlate soil types from one borehole to another, and to extrapolate geotechnical data into outlying areas containing similar soils.

GROUND-WATER CONDITIONS

Liquefaction hazard mapping focuses on areas historically characterized by ground-water depths of 40 feet or less. Accordingly, a ground-water evaluation was performed in the Azusa Quadrange to determine the presence and extent of historically shallow ground water. Data required to conduct the evaluation were obtained from technical publications, geotechnical boreholes, and water-well logs dating back to the turn-of-the- century, namely 1904 ground-water contour maps (Mendenhall, 1908), 1944 ground-water contour maps (California Department of Water Resources, 1966), shallow ground-water maps included in Leighton and Associates (1990), and ground-water level measurements reported in compiled 1960-1997 geotechnical borehole logs.

Shallow ground-water conditions (less than 40 feet depth) were identified in several areas within the Azusa Quadrangle (Plate 1.2). The largest such area covers about 5 square miles encompassing parts of the cities of Azusa, Irwindale, and Duarte. This area represents a joining of several closely spaced areas identified by Tinsley and others (1985), followed by Leighton and Associates (1990), as having historical ground- water depths ranging between 10 feet and 30 feet. The shallow ground-water levels reported here appear to be associated with heavy surface and subsurface water flow originating from the San Gabriel River and ground-water barrier properties of the structurally complex Sierra Madre fault zone. The separate areas were combined into one large area in order to reflect the 40-foot maximum ground-water depth used by DMG in mapping liquefaction susceptibility.

Five much smaller areas characterized by shallow ground-water conditions are situated along the northern margin of the San Gabriel Valley where near-surface sediments are frequently saturated by surface and subsurface waters emanating from Sawpit and adjacent canyons. Upon entering the valley floor, such water quickly descends to great depths through the porous sand and gravel deposits that dominate the valley sediments along the base of the range front.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water-saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Azusa Quadrangle, a peak acceleration of 0.76 g resulting from an earthquake of magnitude 7.0 was used for liquefaction analyses. The PGA and magnitude values were derived from maps prepared by Petersen and others (1996) and Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. The degree of resistance is governed primarily by physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth. Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense. Cohesive soils are generally not considered susceptible to liquefaction.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. DMG's qualitative susceptible soil inventory is summarized on Table 1.2.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. Generally, a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, indicates the presence of potentially liquefiable soil. DMG uses FS, as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil, to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qw	Sandy, silty sand	active stream channels	Loose	Yes
Qf	silty sand, sand, minor clay	active alluvial fans	Loose	Yes
Qyf, Qyf1-4, Qya, Qya1-4	silty sand, sand, minor clay	young alluvial fans and valley deposits	Loose to moderately dense	Yes
Qo, Qvo, Qoa, Qof, Qvof	cobbles, gravel, sand, silt, and clay.	older alluvial fans and valley deposits	Dense to very dense	Not likely

* When saturated.

Table 1.2. General geotechnical characteristics and liquefaction susceptibility of Quaternary sedimentary units.

Of the 5 geotechnical borehole logs reviewed in this study (Plate 1.2), 1 includes blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.
2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.
3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.
4. Areas where existing geotechnical data are insufficient.

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Azusa Quadrangle is summarized below.

Areas of Past Liquefaction

In the Azusa Quadrangle, no areas of documented historic liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

In the Azusa Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Existing Geotechnical Data

Younger alluvial deposits (Qyf, Qyf1-4, Qw) generally have high liquefaction susceptibility. All younger alluvium where ground-water depths historically have been 40 feet or less are included in a liquefaction zone.

Areas without Existing Geotechnical Data

Adequate geotechnical data existed in all areas of the Azusa Quadrangle where young alluvial deposits within 40 feet of the ground surface are or historically have been saturated by ground water.

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SECTION 2

EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Azusa 7.5-Minute Quadrangle, Los Angeles County, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Azusa 7.5-minute Quadrangle (scale 1:24,000). This section and Section

1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Typically, areas most susceptible to earthquake-induced landslides are on steep slopes and on or adjacent to existing landslide deposits, especially if the earth materials in these areas are composed of loose colluvial soils, or poorly cemented or highly fractured rocks. These geologic and terrain conditions exist in many parts of southern California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the Azusa Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus, the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Azusa Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Azusa Quadrangle covers an area of about 62 square miles in central Los Angeles County. Part of the densely populated San Gabriel Valley spreads across the southern quarter of the quadrangle. The remaining three-quarters of the quadrangle contains the rugged terrain of the central San Gabriel Mountains. Most of mountainous part of the quadrangle lies within the Angeles National Forest, except for a fringe of frontal ridges that typically extends less than a mile north of the valley floor. Parts of the cities of Monrovia, Duarte, and Irwindale, as well as the entire City of Bradbury, lie within the valley part of the quadrangle. Primary transportation routes in the quadrangle area are east-west in the San Gabriel Valley, these include major through streets, such as Foothill Boulevard and Duarte Road, and the Foothill Freeway (I-210). Access to the area from the south is via the San Gabriel River Freeway (I-605). San Gabriel Canyon Road (State Highway 39), a major route into the San Gabriel Mountains, leads northward from Azusa.

The San Gabriel Mountains rise very abruptly from the valley and reach elevations of over 5400 feet at Monrovia Peak in the northwest part of the quadrangle. The mountains are composed of igneous and metamorphic rocks that range in age from Precambrian through Cretaceous. The San Gabriel Mountains of today rose to their current elevation beginning in Pleistocene time as the ancient rocks were thrust upward and toward the south along range-bounding faults belonging to the Sierra Madre Fault system. Slopes in the crystalline bedrock are “exceptionally steep and insecure” (Muir, 1877), which, along with periodic torrential rains, leads to periodic debris flows and floods in the valley.

Streams draining from the San Gabriel Mountains have deposited alluvial fans in the valley. The largest stream in the mountains, the San Gabriel River drains a watershed of over 200 square miles. The river enters the valley west of Azusa, and has deposited a large alluvial fan that extends to the south across the valley. The central part of this fan is used for flood control basins, including the Santa Fe Flood Control Basin, ground-water recharge, and sand and gravel mining. The developed areas of the valley are built on the edges of this fan and on the smaller alluvial fan from Sawpit Canyon to the west in Monrovia.

Residential and commercial development is concentrated in the flat-lying valley area. Hillside residential development began before World War II with small developments of single homes or cabins along streams at the base of the San Gabriel Mountains. Hillside development has continued with small residential developments along the mountain front.

The Seismic Hazard Zone Map for the quadrangle has been trimmed back so that it covers roughly the southern two-thirds of the Azusa 7.5-minute Quadrangle. The northern boundary of the zone map is located one to three miles north of the Angeles National Forest Boundary along the San Gabriel Mountain front. The land excluded from the zone map is National Forest land with only a few scattered in-holdings of private property.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

Recently compiled geologic maps were obtained in digital form from the Southern California Areal Mapping Project (SCAMP; Morton and Kennedy, 1989). These maps included the Quaternary geologic map of McCalpin (unpublished) for the Azusa Quadrangle and the geologic map of Morton (1973). These maps were compared with other geologic maps of the area by Dibblee (unpublished), and Crook and others (1987). The mapping was briefly field checked; observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The San Gabriel Mountains in the northern part of the quadrangle are comprised of a complex assemblage of plutonic and metamorphic rocks that are being thrust southward over the adjacent valleys along range-front faults. Bedrock geology in the crystalline bedrock of the San Gabriel Mountains shown by McCalpin (unpublished) is simplified to just one unit called Mx (Mesozoic crystalline rocks). Morton (1973) mapped the south half of the quadrangle, showing the bedrock geology in great detail, and also showing the location of contacts between crystalline rocks and Quaternary deposits with more detail than McCalpin. We were not able to obtain a detailed map of bedrock units in the north half of the quadrangle for this compilation. A less detailed map by Dibblee (unpublished) was obtained from the DMG Regional Mapping Program files and digitized. In order to show as much detail in the bedrock as feasible, and show contacts as accurately as possible, the completed geologic map for this evaluation primarily used the boundaries between the geologic units as mapped by Dibblee (unpublished) and Morton (1973) in the mountainous areas and McCalpin in the valley. Unit designations are from Morton (1973) for the bedrock units.

Major crystalline bedrock units mapped by Morton (1973) in the Azusa Quadrangle include gneissic rocks, mapped as undifferentiated biotite and hornblende gneiss, calc-silicate marble and amphibolite (m2, m2a, and qd+m2, gneissic quartz monzonitic rock (m1f), mixed biotite and hornblende gneiss (m1e), cataclastic rock (m1d), biotite gneiss (m1c), mixed gneissic quartz diorite and gneiss (m1b), hornblende gneiss (m1a), and a mixture of intensely fractured gneiss and quartz diorite (qd1). These highly metamorphosed rocks have been intruded by igneous rocks mapped as granodiorite (grd), quartz monzonite (qm), quartz diorite (qd), gabbro (dgb), and leucogranitic rocks (g).

Dikes of basaltic rocks (Td1) and leucocratic rock (Td2) cut the older plutonic and metamorphic rocks.

Overlying the metamorphic and intrusive rocks are volcanic and sedimentary rocks of Miocene age. These include basalts and dikes of the Glendora Volcanics (Tg, Tgb, Tgf, and Tgi) and bedded marine sandstone and siltstone of the Topanga Formation (Tt). Conglomerate of possible Pliocene age crops out in the Bradbury area, where Morton (1973) designated it the Duarte Conglomerate (Tdc).

Surficial units in the mountainous areas include colluvium (Qc), talus (Qta), and stream deposits in the canyons. Stream deposits are typically sand and gravel in the active channel (Qw, Qwg) and raised terrace deposits of young alluvium (Qyf2) and older alluvium (Qoa1) above modern channel levels.

The valley areas of the Azusa Quadrangle are covered by alluvial fans of various ages, including remnants of very old fans along the front of the San Gabriel Mountains (Qofg), older alluvial surfaces (Qoa, Qao, Qoag, Qoa2, Qvoa1, Qvoa2), younger alluvium (Qsw, Qal, Qyag, Qya1g), and younger fans (Qf, Qfg, Qyf, Qyf1,Qyf3, Qyf3a, Qyf3g, Qyf4g, Qyfg), including the major San Gabriel River fan. A more detailed discussion of the Quaternary deposits in the Azusa Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they must first be ranked on the basis of their overall shear strength. The primary source for rock shear-strength measurements is geotechnical reports prepared by consultants, on file with local government permitting departments. Shear strength data for the rock units identified on the geologic map were obtained from the Los Angeles County, City of Azusa, and City of Duarte Departments of Public Works (see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above sources were compiled for each mapped geologic unit, and subdivided for fine-grained and coarse-grained lithologies if appropriate. Geologic units were grouped on the basis of average angle of internal friction (average f) and lithologic character. Geologic formations that had little or no shear test information were added to existing groups on the basis of lithologic and stratigraphic similarities.

To subdivide mapped geologic formations that have both fine-grained and coarse-grained lithologies, we assumed that where stratigraphic bedding dips into a slope (favorable bedding) the coarse-grained material strength dominates, and where bedding dips out of a slope (adverse bedding) the fine-grained material strength dominates. We then used structural information from the geologic map (see “Structural Geology”) and terrain data in the form of slope gradient and aspect, to identify areas with a high potential for containing adverse bedding conditions. These areas, located on the map, were then used to modify the geologic material-strength map to reflect the anticipated lower shear strength for the fine-grained materials. In the Azusa Quadrangle, only the Topanga Formation displayed the appropriate material and bedding conditions to analyze for dip slope conditions.

The crystalline rocks of the San Gabriel Mountains have undergone repeated tectonic movement and compression, resulting in a pervasive fracturing, which imparts a common strength characteristic to all the rock units. The tectonic history dominates other characteristics related to age and mineralogy. Based on shear test results obtained for the Azusa and other nearby quadrangles, and on phi values for similar rock types published in rock mechanics books (Franklin and Dusseault, 1989; Hoek and Bray, 1981; and Jumikis, 1983), all the crystalline rocks of the San Gabriel Mountains were grouped into one strength group, designated "gr", for the landslide evaluation for the Azusa Quadrangle.

Average phi values calculated from tests taken in adjacent quadrangles were used to characterize those units in the Azusa Quadrangle for which shear test data were not available. These units included the Glendora Volcanics, and the Topanga Formation.

Existing landslides (Qls) were assigned a phi of 14 for stability analysis calculations for this quadrangle. None of the geotechnical reports reviewed for the quadrangle contained any direct shear tests run on actual slide plane material, but there were a few such test results for nearby quadrangles. The phi values for slide plane material actually tested displayed a wide range, and 14 was near the low end of this range. In those geotechnical reports that provided slope stability calculations, conservative assumed phi values were generally chosen, and 14 was again on the low end of the range of values used.

The results of the grouping of geologic materials in the Azusa Quadrangle are in Tables 2.1 and 2.2.

AZUSA QUADRANGLE SHEAR STRENGTH STATISTICS

	Formation Name	Number of Tests	Mean/ Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP A	gr*	0		38	160		38
GROUP B	Qa*	30	33.9/33.5	34	289/240	Tt_fbc, Tg, Tdc	34
GROUP C	Tt_abc, F, f*	0		27	500		27
GROUP D	Qls	0		14	400		14**

Abc = adverse bedding condition, fine-grained material strength
Fbc = favorable bedding condition, coarse grained material strength
gr* = pre-Tertiary crystalline units
Qa* = af (fill) and Quaternary units
F, f* = shear and fault zone material
** = lowest calculated phi vaule was accepted as representative phi value for landslides

Table 2.1. Summary of the shear strength statistics for the Azusa Quadrangle.

SHEAR STRENGTH GROUPS FOR THE AZUSA QUADRANGLE			
GROUP A	**GROUP B**	**GROUP C**	**GROUP D**
dab, a, ard, am ad, ad1 m1b, m1c, m1d m1e, m1f m2, m2a Td1	Ta Tab Taf Tai Tt-fbc Tdc af Qc, Qsw, Qta Qw, Qwg Qal, Qvag, Qya1g Qoa, Qoa1, Qoag, Qoa2 Qvoa1, Qvoa2 Qf, Qfg, Qyf, Qyf1 Qyf2, Qyf3, Qyf3a, Qyf3g, Qyf4g, Qyfg	Tt_abc F, f	Qls

Table 2.2. Summary of the shear strength groups for the Azusa Quadrangle.

Structural Geology

Structural geologic information, including bedding and foliation attitudes (strike and dip) and fold axes, provided on geologic maps by Morton (1973), along with field checking of rock units, were used to determine which rock units might display adverse bedding conditions. The crystalline rocks of the San Gabriel Mountains are massive to moderately foliated, with no obvious pattern of change in slope stability conditions related to changes in foliation attitude. Therefore, dip slope analysis was not performed on crystalline bedrock of the San Gabriel Mountains. Likewise, rock units of the Glendora Volcanics are not suited to dip slope analysis, because the structure is generally chaotic, owing to the heterogeneous nature of original emplacement. The bedded Topanga Formation did display alternating weak and strong layers, with lateral continuity of layering, that warranted dip slope analysis. We used the structural geologic information provided on the geologic map to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of existing landslides in the Azusa Quadrangle was prepared (Treiman, 1998) by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. Aerial photos taken by the U.S. Department of Agriculture (1952/53) were the primary source for landslide interpretation. Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Morton and Streitz, 1969; Morton, 1973; and Crook and others, 1987). The completed hand-drawn landslide map was scanned and digitized by the Southern California Areal Mapping Project (SCAMP) at U.C. Riverside. The landslide database was attributed with information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s). All landslides on the digital geologic map (Morton,1973) were verified or re-mapped during preparation of the inventory map. To keep the landslide inventory of consistent quality, all landslides originally depicted on the digitized geologic map were deleted, and only those included in the DMG inventory were incorporated into the hazard-evaluation process. A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Azusa Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.0 to 7.1
Modal Distance:	2.5 to 6.1 km
PGA:	0.63 to 0.82 g

The strong-motion record selected was the Channel 3 (north horizontal component) Pacoima-Kagel Canyon Fire Station recording from the magnitude 6.7 Northridge earthquake (Shakal and others, 1994). This record had a source to recording site distance of 2.6 km and a PGA of 0.44 g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.074, 0.13 and 0.21 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the significant ground-shaking opportunity thresholds for the Azusa Quadrangle.

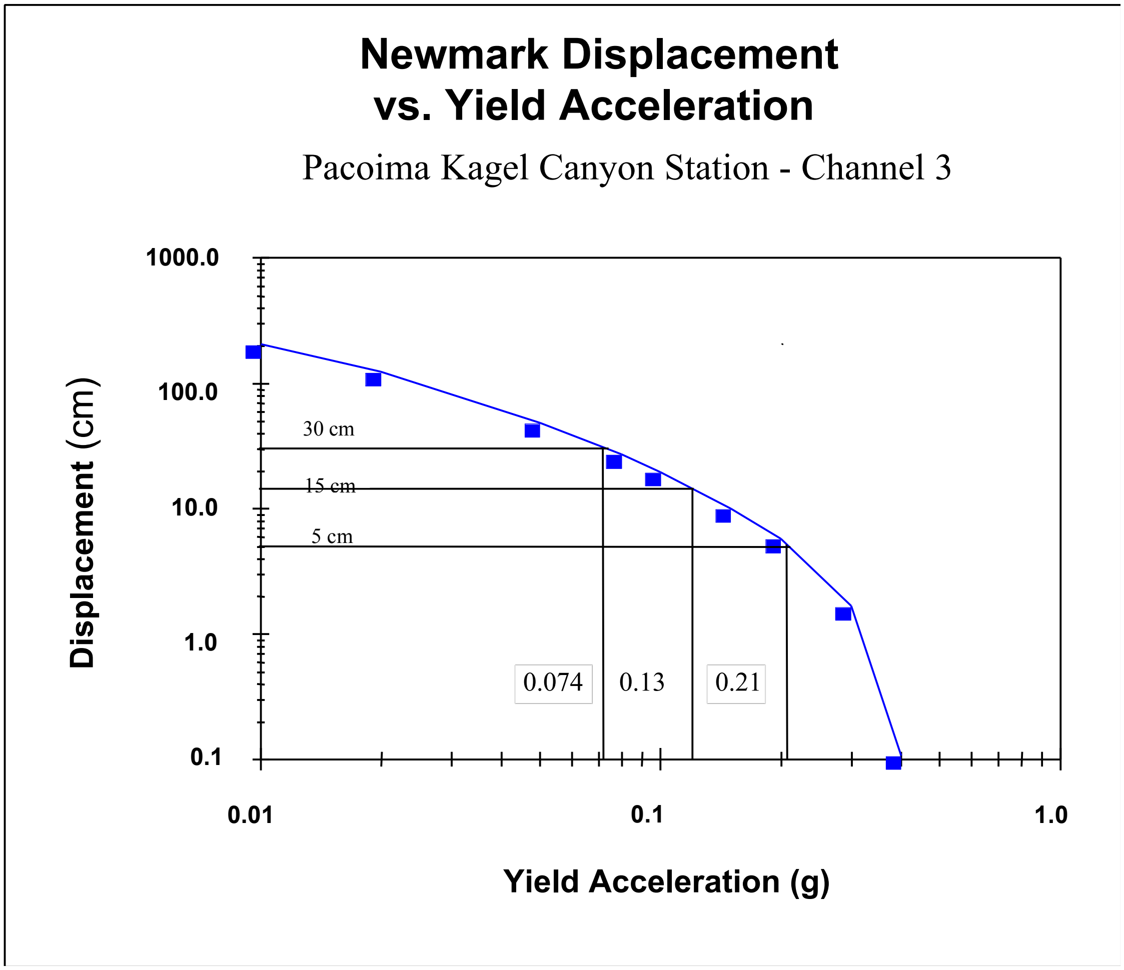

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Pacoima-Kagel Canyon Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake. Record from California Strong Motion Instrumentation Program (CSMIP) Station 24088.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Azusa Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle contours, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. Surrounding quadrangle DEMs were merged with the Azusa DEM to avoid the loss of data at the quadrangle edges when the slope calculations were performed. A peak and pit smoothing process was then performed to remove errors in the elevation points.

To update the topographic base map, areas that have undergone large-scale grading as a part of residential development in the hilly portions of the Azusa Quadrangle were identified (see Plate 2.1). Using 1:40,000-scale NAPP photography taken in June, 1994, and October 1995, photogrammetric DEMs covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by DMG. The photogrammetric DEMs were then merged into the USGS DEM, replacing the areas of out-dated elevation data.

A slope-gradient map was made from the combined DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). This map was used in conjunction with the geologic strength map in preparation of the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.074g, expected displacements could be greater than 30cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.074 and 0.13g a MODERATE (M on Table 2.3) hazard potential was assigned, between 0.13 and 0.21 a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than 0.21g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

AZUSA QUADRANGLE
HAZARD POTENTIAL MATRIX

		SLOPE CATEGORY									
Geologic Material Group	**Mean Phi**	**I 0-18**	**II 18-29**	**III 29-37**	**IV 37-44**	**V 44-52**	**VI 52-54**	**VII 54-59**	**VIII 59-63**	**IX 63-69**	**X >69**
1	38	VL	VL	VL	VL	VL	VL	L	L	M	H
2	34	VL	VL	VL	VL	L	M	M	H	H	H
3	27	VL	VL	L	M	H	H	H	H	H	H
4	14	L-M	H	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Azusa Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (in press). Under those criteria, earthquake-induced landslide zones are areas meeting one or more of the following:

1. Areas known to have experienced earthquake-induced slope failure during historic earthquakes.

2. Areas identified as having past landslide movement, including both landslide deposits and source areas.

3. Areas where CDMG's analyses of geologic and geotechnical data indicate that the geologic materials are susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

It is likely that minor rockfalls from steep canyon walls in the western half of the quadrangle were triggered by the $5.8M_L$ Sierra Madre earthquake of June 28, 1991 because rockfalls and dust clouds were observed in the adjacent Mt. Wilson Quadrangle (Allan Barrows, personal communication, 1998).

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic strength group 4 is always included in the zone (mapped landslides): strength group 3 materials are included in the zone for all slope gradients above 29%; strength group 2 materials are included in the zone for all slope gradients above 44%; and strength group 1 materials—the strongest rock types—are zoned for slope gradients above 54%.

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APPENDIX A
SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Azusa, Public Works	**7**
City of Duarte, Public Works	**5**
Los Angeles County Public Works Department	**18**
Total number of tests used to characterize the units in the Azusa Quadrangle	**30**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Azusa 7.5-Minute Quadrangle, Los Angeles County, California

By

Mark D. Petersen, Chris H. Cramer, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles.

They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage:
http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

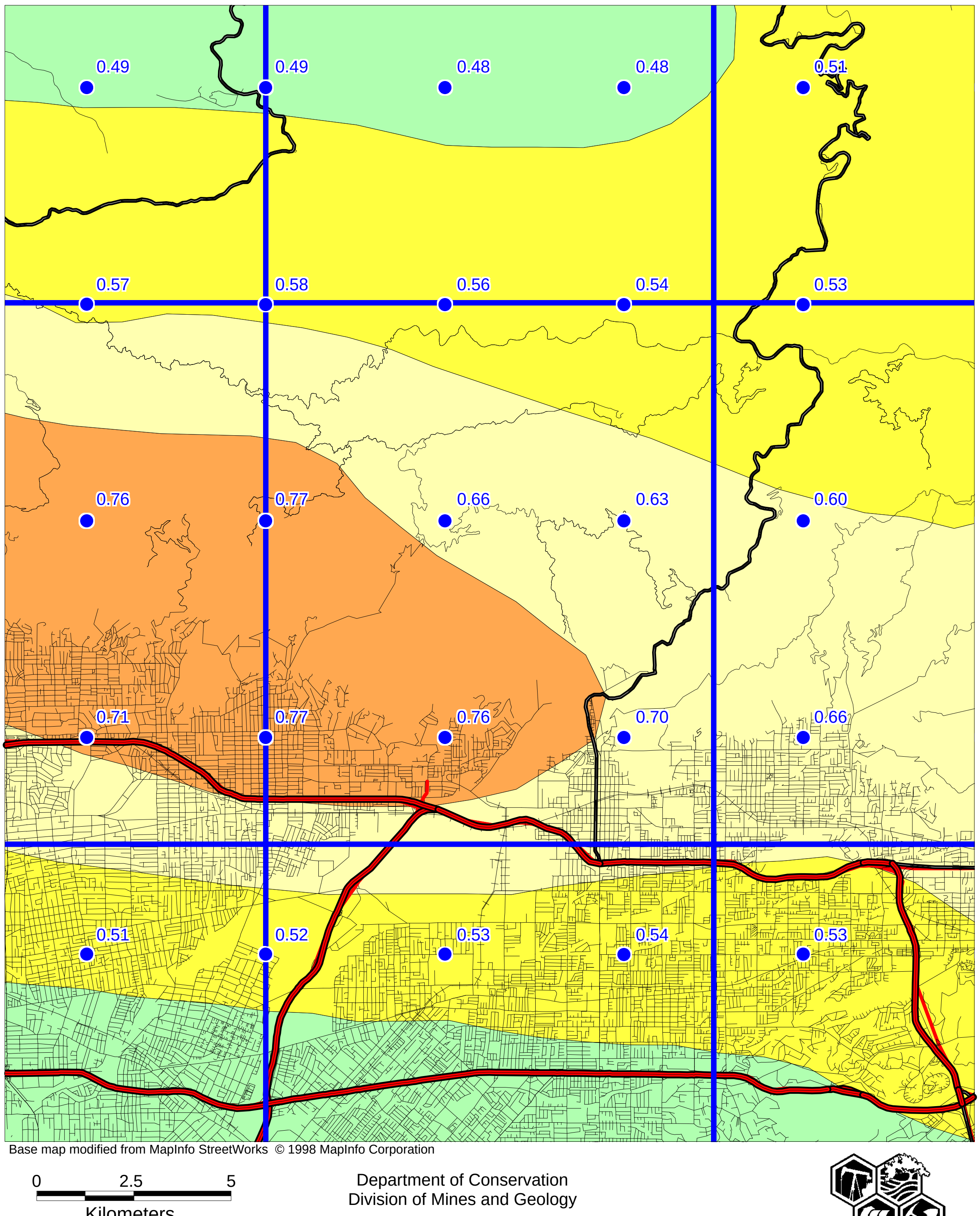
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

AZUSA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

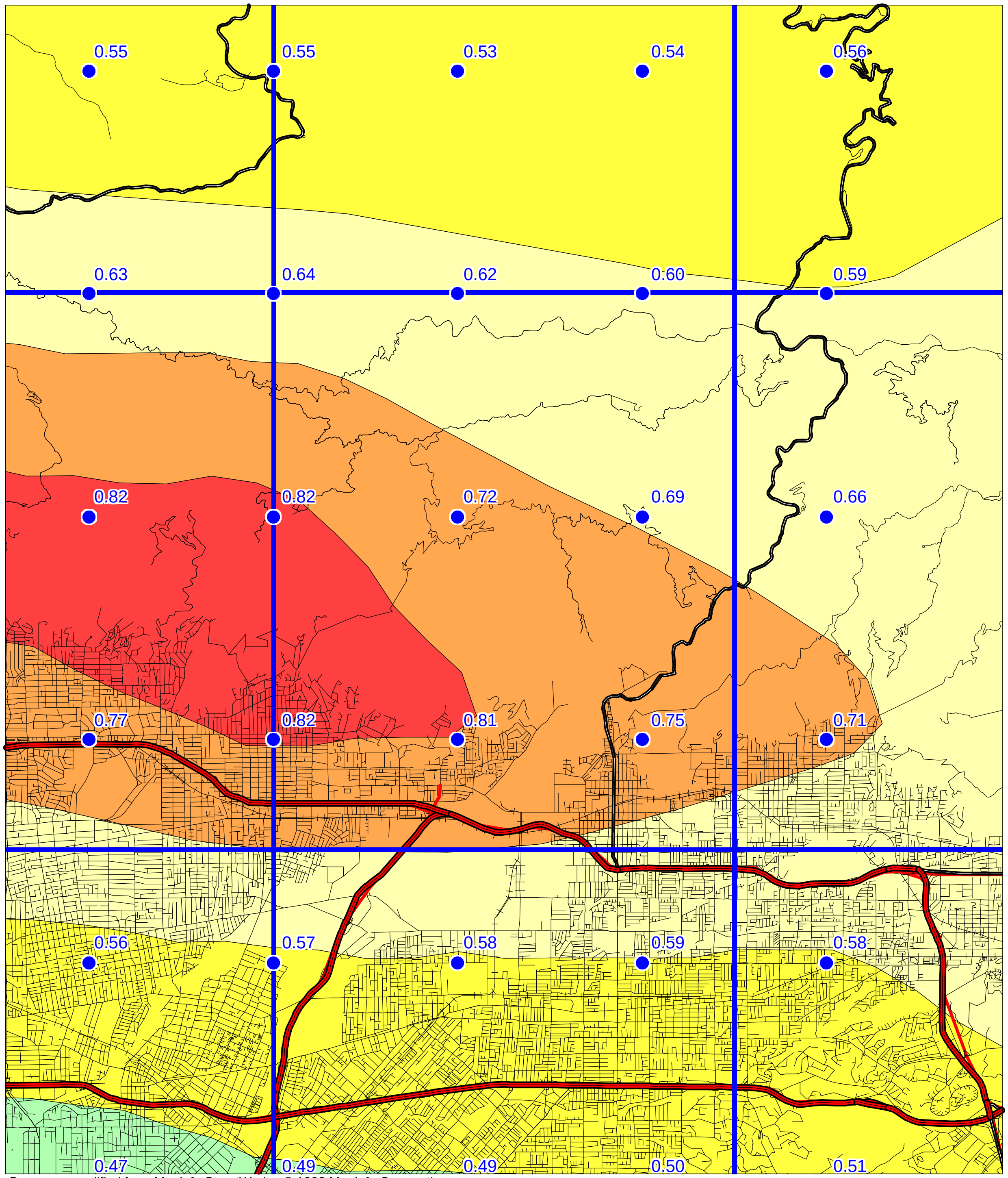
Figure 3.1

AZUSA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

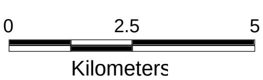
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation



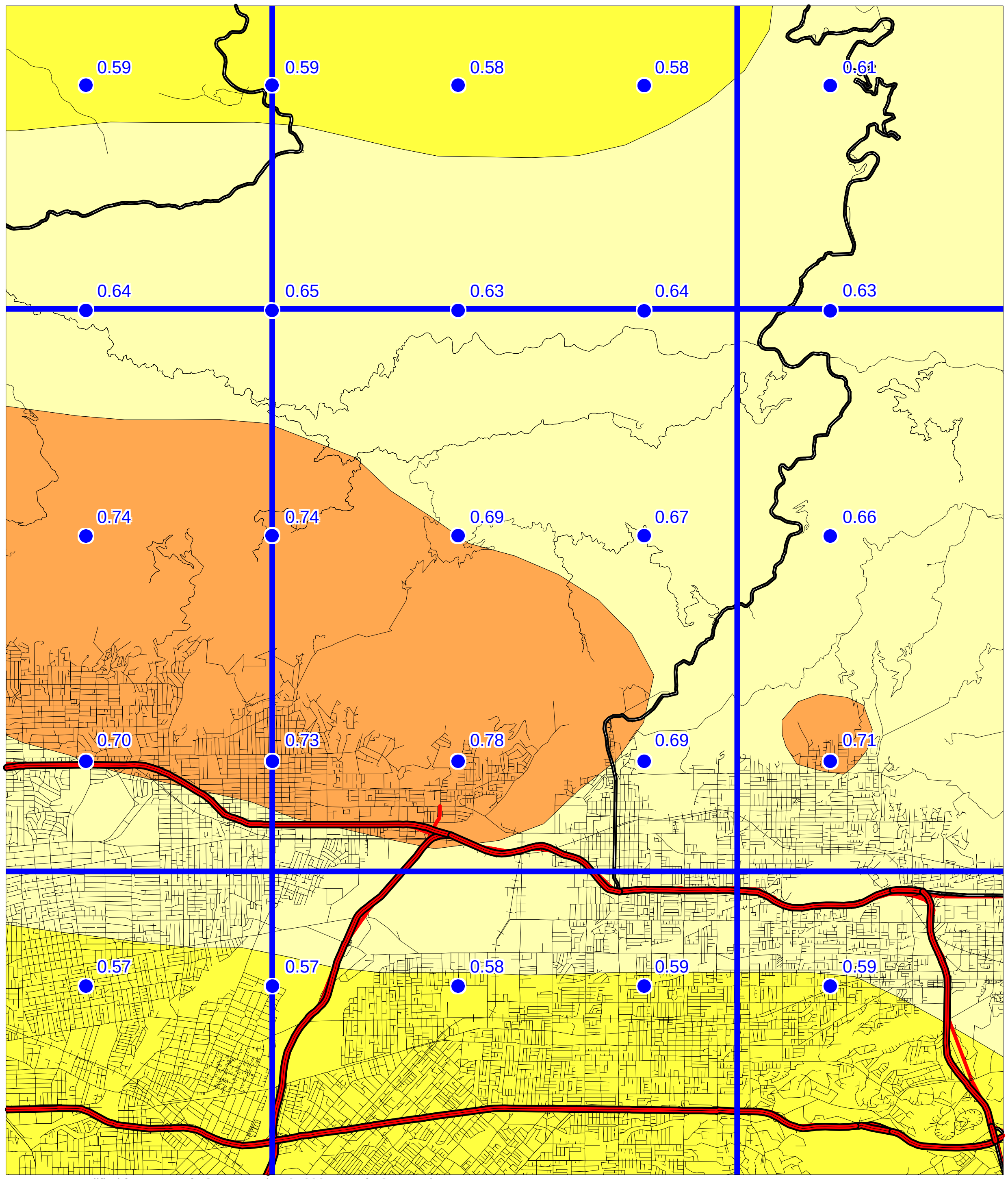
Department of Conservation
Division of Mines and Geology

Figure 3.2

AZUSA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

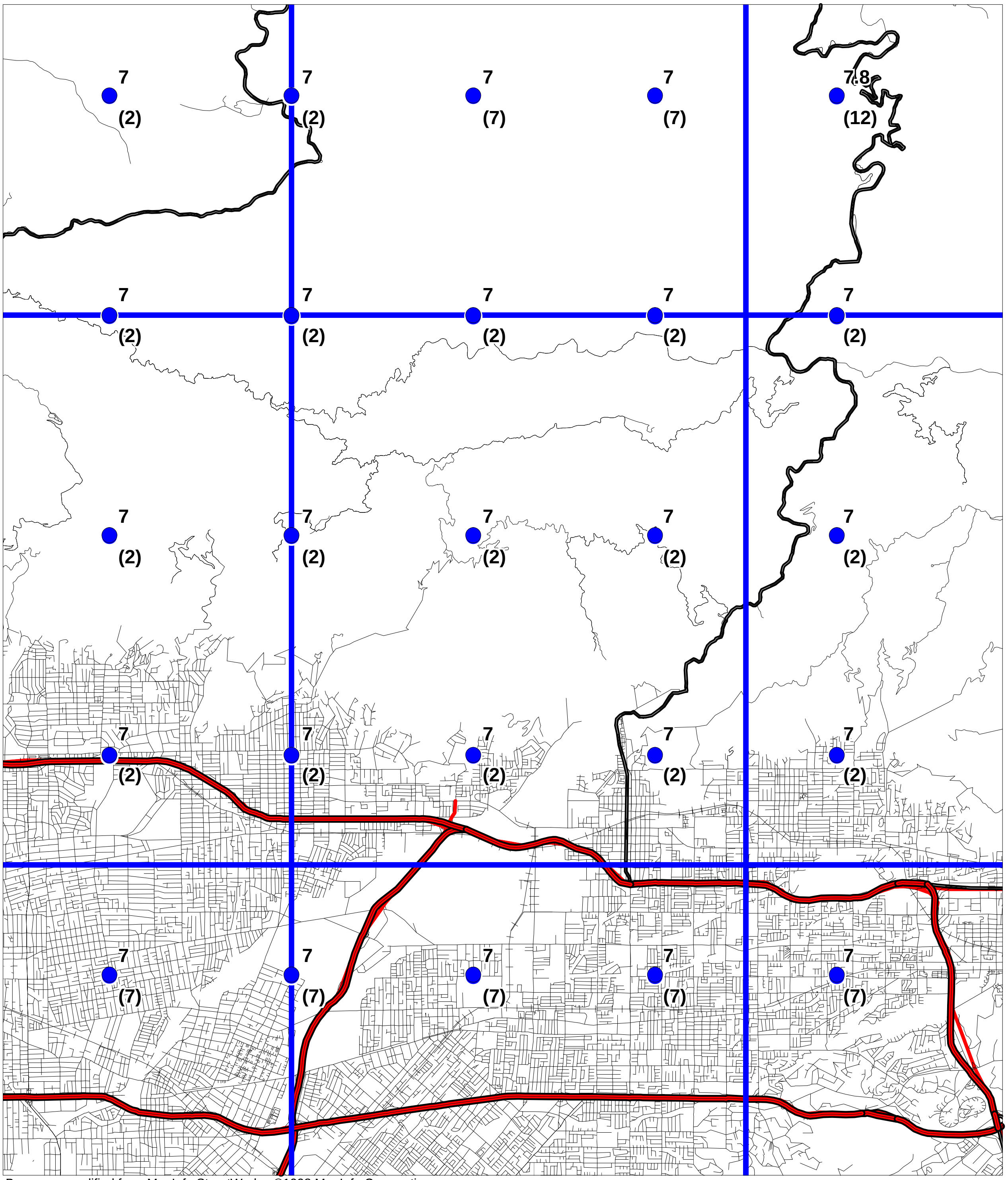
1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values

AZUSA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.4

may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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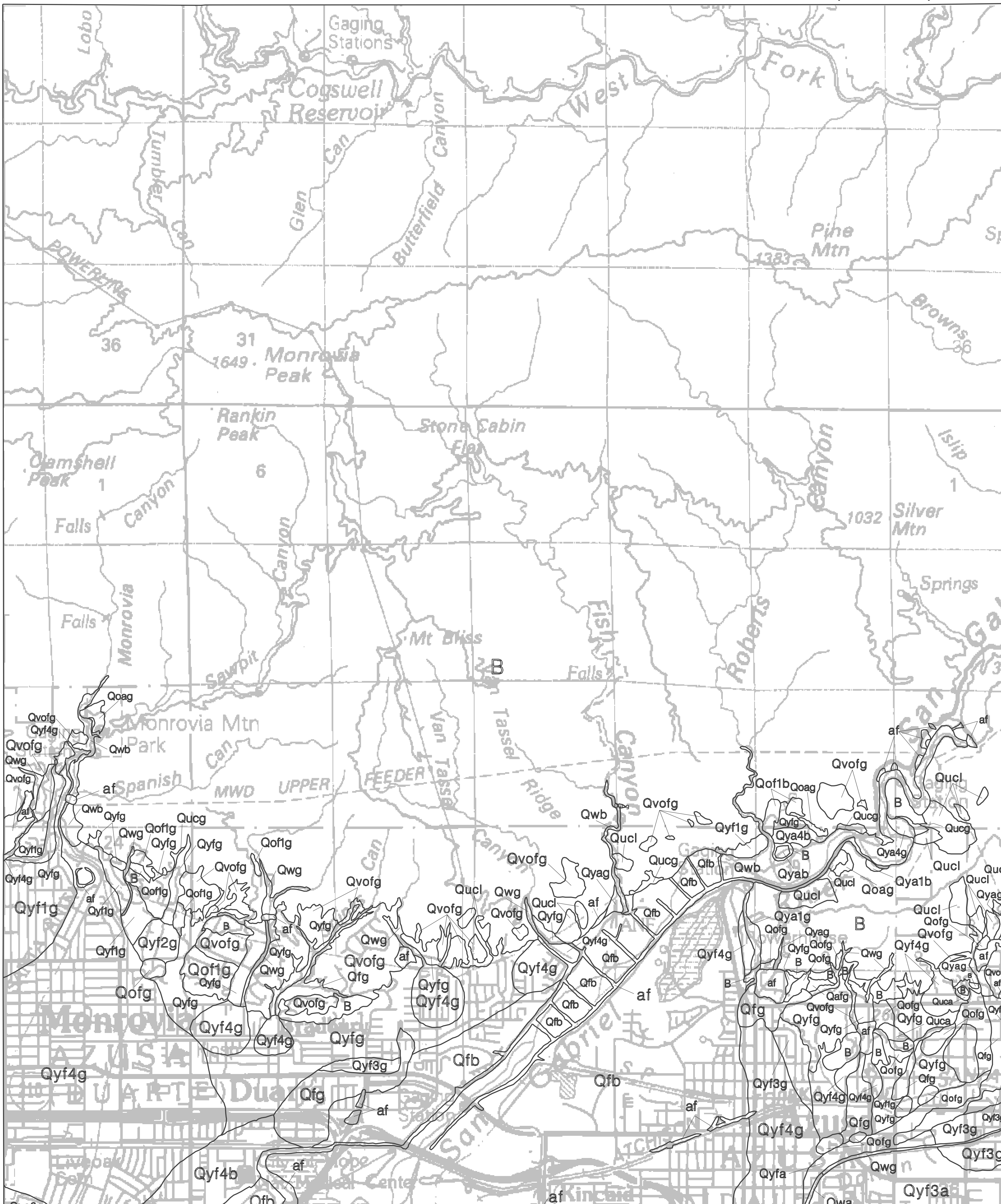


Base map enlarged from U.S.G.S. 30 x 60–minute series

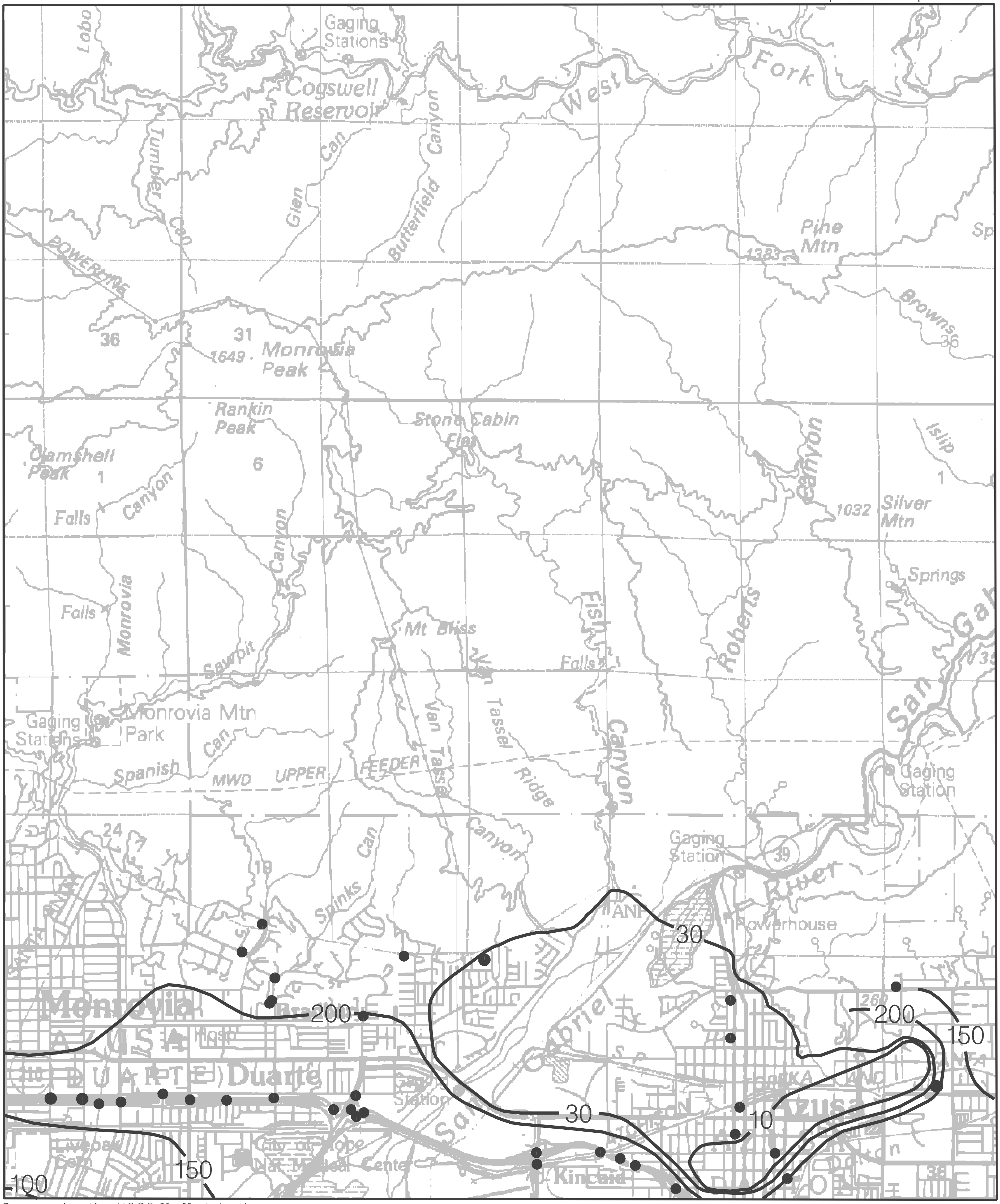
Plate 1.1 Quaternary Geologic Map of the Azusa Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

B = Pre–Quaternary bedrock.

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Azusa Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE

Plate 2.1 Landslide inventory, Shear Test Sample Locations, and Areas of Significant Grading, Azusa Quadrangle.

shear test sample location
landslide
areas of significant grading
tract report with multiple borings

ONE MILE

SCALE